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UNITED STATES
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INFORMATION CIRCULAR

SOME INFORMATION ON THE CAUSES AND PREVENTION OF FIRES AND EXPLOSIONS IN THE PETROLEUM INDUSTRY

BY

G. M. KINTZ

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UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

SOME INFORMATION ON THE CAUSES AND PREVENTION OF FIRES AND EXPLOSIONS IN THE PETROLEUM INDUSTRY[1]

By G. M. Kintz[2]

INTRODUCTION

It is estimated that 10,000 lives were lost and $285,000,000 worth of property was destroyed by fire in 1937. Of the 103 fatalities in the petroleum industry in 1938, 36 resulted from fires and explosions.[3]

Everyone can help to prevent the tremendous losses, both in life and property, caused annually by fires and explosions. Forest fires occur every year, in which the tremendously intense heat wave ahead of the flame turns beautiful green trees into blazing torches like so much gasoline vapor and jumps over the tops of trees to start fires behind the fire fighters; prairie-grass fires occur, and a farmer in the path of the fire must plow a furrow around his home and outbuildings before the flame reaches them; and frequently automobiles are burned up in filling stations. Persons who have witnessed such sights know better than to throw a lighted match, cigarette, cigar, or hot coal from a pipe out of an automobile or to discard a fire or flame of any type in the forest, in the country, or in the city.

"No smoking" signs and requests to extinguish camp fires and burning or smoldering substances are not posted to reform people but to protect them and their property; probably no injury, fatal or otherwise, causes more agony than burns.

Gas, gasoline, and electricity are faithful servants that are ever ready to serve man with absolute safety as long as they are handled intelligently, BUT they are some of man's most destructive enemies if not handled according to certain simple rules some of which are outlined in this paper.

ACKNOWLEDGMENTS

The writer wishes to thank the following persons, organizations, and companies for their assistance in making this report possible: Petroleum

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[1] The Bureau of Mines will welcome reprinting of this paper provided the following footnote acknowledgment is used: "Reprinted from Bureau of Mines Information Circular 7150."

[2] Mining engineer, Health and Safety Branch, Bureau of Mines Safety Station, Dallas, Tex.

[3] American Petroleum Institute, Review of Fatal Injuries in the Petroleum Industry for 1938: Dept. of Accident Prevention, 50 West 50th St., New York, N. Y., June 1939, 16 pp.

Division, Bartlesville station, Federal Bureau of Mines, for the construction of the gasoline trough and inflammable-limits chamber and for the use of certain chemical equipment; electrical section, Bureau of Mines, Pittsburgh, Pa., for the use of the explosion chamber in demonstrating the hazards of electric equipment; Lone Star Gas Co., Dallas, Tex., for the loan of a small tank containing butane gas and for a reducing valve; American-LaFrance & Foamite Co., Dallas, Tex., for the loan of a miniature Foamite extinguisher and for supplying solutions to use in it, also for the loan of a 10-pound carbon dioxide fire extinguisher with frequent recharges; Technical Products Co., Inc., Dallas, Tex., for the use of an extinguisher and other material; Mine Safety Appliances Co., Dallas, Tex., and B. F. McDonald Co., Houston, Tex., for the loan of Edison cap lamps using storage battery and dry cell and for a safety hat; and E. D. Bullard Co., Houston, Tex., for the loan of a Wheat storage-battery hand lamp, belt lamp, and charger. Some of the ideas for basic material for this report were obtained from a paper read by John T. Howell, Union Oil Co. of California, before the Petroleum Section of the National Safety Council at Kansas City, Mo., October 13, 1937.

The writer is especially indebted to James M. Seward, principal engineering draftsman, Petroleum Division, Bureau of Mines, Dallas, Tex., for the figures in this paper.

FIRES AND EXPLOSIONS

Some dictionaries give as many as 14 definitions for the word "fire"; however, Webster's definition of fire as "the principle of combustion as manifested in light, especially flame, and in heating, destroying, and altering effects" is fairly satisfactory.

CONDITIONS ESSENTIAL TO FIRE

Presence of Fuel

It is obvious that to have a fire there must be some form of combustible matter to burn as fuel.[4] This requirement for a fire (restricting the discussion to fuels) may be represented by a horizontal line with the word "fuel" beneath the line.

Fuel

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[4] Howell, John T., fire-protection engineer, Union Oil Co. of California, Causes, Prevention, and Control of Petroleum Fire: Paper delivered before the Petroleum Section of the National Safety Congress at Kansas City, Mo., October 13, 1937. Howell discussed "fire" and its component parts and performed the experiments described in this paper on pages 2 to 29, except as noted. It is desired to give full credit and thanks to him and his company for permitting the use of this splendid material.

Reference is made also to Burrell, G. A., **Hazards in Handling Gasoline**, Bureau of Mines Tech. Paper 127, 1915, 17 pp. Burrell discusses hazards along the same line of though as Howell, although not as completely.

It is well-known that the petroleum industry originated in the production of kerosene. Many persons have seen kerosene used in lamps to give light and in stoves to give heat, yet when kerosene is poured into a pan to a depth of about 1/4 inch and a burning match held directly above the kerosene, it does not ignite. When the burning match is plunged into the kerosene the match flame is extinguished, hence kerosene as a liquid does not burn.

If the same procedure is followed with a lighter product, such as a well-known solvent (commonly used as a cleaning fluid), which according to the laws of Texas must have a flash point of at least 110° F., the result is the same.

A wick saturated with kerosene bursts into flame when a match is applied to it. If part of a calling card is passed through a flame it does not fire immediately, but if it is dipped into the kerosene, the excess fluid shaken off, and the dampened end held close to the flame of a Bunsen burner, IT FIRES IMMEDIATELY. When the burning card is dipped into kerosene the flame is extinguished, and examination of the card shows that it is not even charred, yet a fuel must have been present because a fire occurred. This behavior can be explained by assuming that when the moistened card is held near the flame the fine film of liquid is heated to a high enough temperature to turn a small part of it into vapor and it bursts into flame. That this is true is deduced from the fact that the card was not charred and the liquid itself did not burn.

If this assumption is true, the solvent in the pan may be heated to 110° to 115° F. - about the temperature of water for washing or shaving - and it will give off a vapor that will ignite when a lighted match is held to the edge of the pan. (Note: In performing this experiment it is necessary to take care that the vapors are not ignited by the flame when heating the solvent.) It thus appears that liquids and solids do not burn until certain conditions are fulfilled.

When wood is shaved (with a pocket knife or other instrument) and the shavings are held in a flame they will ignite. Wood contains alcohol, turpentine, and other volatile materials, which when heated turn to a vapor; hence, in a finely divided state, wood is ignited readily when in contact with sufficient heat. This is true of other solid or liquid materials composed entirely or partly of inflammable substances.

Many oils and other fluids emit inflammable vapor at ordinary temperatures; these include gasoline, benzene, alcohol, paints, lacquers, and numerous household and manufacturing fluids.

Gasoline should never be carried in a glass jar or bottle, whether open or sealed; and it should not be carried or transported in a screwed-top, unvented, or unapproved tin can. Glass jars break or may explode, and vapor-tight tin cans may blow up. Many containers of approved types are available; in some approved containers the top is held in a closed position by a spring, thereby preventing leakage of the liquid and at the same time releasing excessive gas pressure. If the vapors are ignited while liquid is poured from a container of this type, the fire can be extinguished by releasing the handle, thus permitting the cover to close automatically and probably preventing the fire from entering the container. When a small quantity of gasoline is poured into a frying pan and a burning match moved toward the pan, the vapors will ignite a short distance from the edge of the pan, the gasoline vapors or fine particles and not the liquid taking fire; therefore, the straight horizontal line diagram can be modified by inserting in parenthesis the word "vapor" after the word "fuel".

Fuel (vapor)

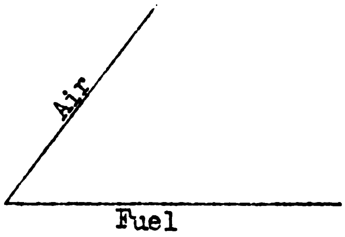
Thus, to have a fire it is necessary to have a fuel, and even a fuel will not burn unless certain conditions are satisfied; one of the conditions for gasoline or similar liquids is that the material be in the form of an inflammable vapor or gas.

Presence of Air

When a small glass jar such as a mayonnaise container is partly filled with gasoline and an arcing automobile spark plug is placed inside the jar just above the liquid and in pure gasoline vapor, no ignition takes place. (To perform this experiment an automobile spark plug fastened to a wand, as shown in figure 1, is inserted in the jar, and current is used to energize the spark coil to which the spark plug is connected. The glass jar should be set in a shallow pan so that if spillage takes place the liquid gasoline will not spread unduly.)

It has been shown that gasoline vapors burn, but as the arcing plug is slowly raised no ignition takes place until the plug is well above the top of the jar; when the cover is replaced on the jar the fire is extinguished almost immediately. It is evident that the significant material above the jar that is separated from the fuel by replacing the lid is AIR.

A fire requires not only fuel but also air or at least the oxygen contained in the air. This relationship between fuel and air can be illustrated diagrammatically by placing a line marked "air" at an angle with the "fuel" line.



Normal air contains approximately 21 percent oxygen and 79 percent nitrogen or inert gas. If a gallon jar is filled with pure nitrogen and a burning match or candle inserted in the jar, the flame will be extinguished, showing that the nitrogen will not support combustion. When a quart jar is filled with pure oxygen and a burning match or candle is placed in it, the flame will burn violently and with great brilliance; therefore, it is evident

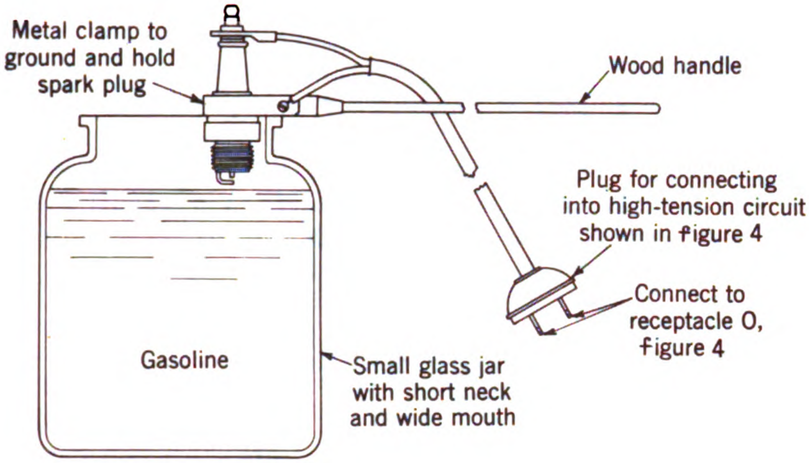

Metal clamp to ground and hold spark plug
Wood handle
Plug for connecting into high-tension circuit shown in figure 4
Connect to receptacle O, figure 4
Gasoline
Small glass jar with short neck and wide mouth

Figure 1.- Diagram of equipment for demonstrating that gasoline and similar vapors will not burn unless properly mixed with air.

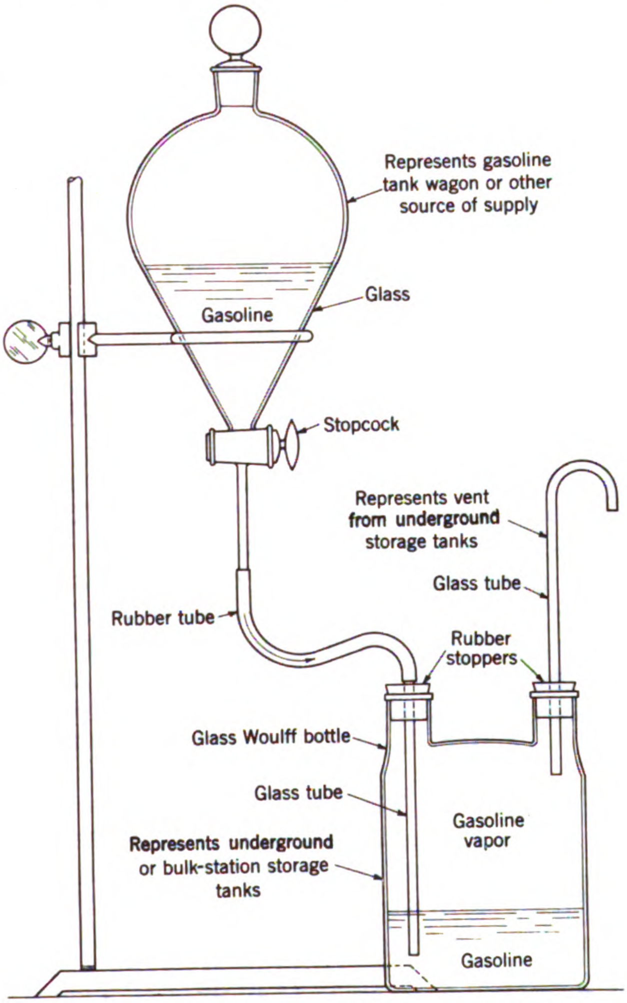
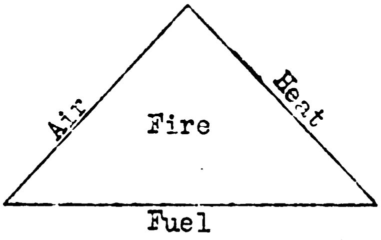

Represents gasoline tank wagon or other source of supply
Gasoline
Glass
Stopcock
Represents vent from underground storage tanks
Glass tube
Rubber tube
Rubber stoppers
Glass Woulff bottle
Glass tube
Gasoline vapor
Represents underground or bulk-station storage tanks
Gasoline

Figure 2.- Diagram of equipment for demonstrating that removal of fuel will extinguish a fire and that a flame will not travel down the vent pipe into a gasoline storage tank while it is being filled or gasoline vapors are escaping from the vent pipe.

that the oxygen in the air supports combustion. If a gallon jar of pure nitrogen is connected to a quart jar of pure oxygen and the jars are permitted to stand until their contents are thoroughly mixed, a burning match or candle placed in either jar will continue to burn in essentially the same manner as in normal air; however, the mere presence of an inflammable vapor or gas in air at ordinary temperature containing oxygen does not produce a fire, as is illustrated by exposing a pan of gasoline to the air or by allowing illuminating gas to issue from a jet into the air, as neither will burn unless a flame is present.

Presence of Heat

Another essential for a fire is HEAT. The heat can be generated in many ways - by chemical reaction, the flame of a match, an electric arc, or a heated filament. (To illustrate this, a bunsen burner is reignited by the spark plug and the pan of gasoline by a burning match.) The triangle diagram can be completed by adding the third leg and marking it "heat", then inserting the word "fire" on the inside as follows:



When an inflammable vapor in air comes in contact with enough heat, a fire or explosion will occur; however, by removing any element comprising one of the legs of the triangle the fire will be extinguished; in other words, the triangle will collapse.

Fire can be created only by having fuel, air, and enough heat to raise the temperature to the ignition point together at the same instant. This information can be used to explain many fires in daily life that have appeared somewhat mysterious. For example, an electric spark may occur inside of a container partly filled with a volatile liquid such as gasoline. No fire or explosion will take place as long as the atmosphere contains too rich a mixture of inflammable gas; however, if the spark is held outside of the container or at any point where the inflammable vapor or gas is mixed with air in certain proportions, a fire or explosion will occur.

This point can be illustrated further. If the tires of a gasoline-filled tank-wagon truck catch fire and continue to burn, the heat from the flames will be transmitted to the tank. The gasoline will then expand and vaporize and an explosion may occur; however, the tank will not explode if it is equipped with effective relief valves.

Vessels that are full or partly full of inflammable fluids do explode but so do vessels such as boilers that contain water and steam and air receivers that contain air. Tanks containing inflammable vapor or gases explode for essentially the same reasons that boilers, compressed-air tanks, or similar vessels rupture either because of structural defects or weaknesses in the vessels or excessive pressure with improper vents or safety valves to relieve the pressure and not necessarily because of the nature of the liquid or the gas they contain.

Liquids used in everyday life, when heated to a high enough temperature, will turn to gases that also expand as temperature increases. When the water in a boiler gets too low and the crown sheet becomes red hot, if water is added and touches the hot metal the water changes to steam so rapidly that excessive pressures cannot always be relieved by safety valves before the vessel ruptures.

Under ordinary conditions water in the form of vapor will not burn; in fact, water vapor will extinguish most fires; however, under some conditions such as the impingement of water on very highly heated surfaces, the water may be decomposed into its component elements, oxygen and hydrogen, with subsequent explosion of the highly flammable hydrogen gas. As stated, gasoline, alcohol, and similar fluids vaporize at ordinary room temperatures, and if heat is applied they will vaporize more rapidly.

Tank trucks catch fire in many ways: The tires or brakes may get too hot and catch fire; material that spills or leaks may be ignited by the hot exhaust; the wiring may be faulty; or a collison may occur.

By drawing a cross section of a tank-wagon truck and assuming a fire beneath it, the similarity between such a fire and the fire of a Bunsen burner under a small flask of water can be shown. If the opening in the flask is stoppered by a cork with a hole through it, the water upon being heated will gradually turn to steam which will escape without an explosion; however, if the cork is replaced with one that is solid and heat is applied, enough pressure will build up inside the vessel to blow the cork out or break the flask; in other words, an explosion will occur. (When performing this experiment the cork should not be inserted very tightly.) When any vessel explodes, excessive pressure builds up until something gives way; in this experiment the sudden release of pressure causes a large percentage of the water to be thrown out of the vessel.

If a tank of gasoline, crude oil, or other inflammable liquid explodes because of improper vents, the heated liquid may be sprayed over a considerable area and a destructive fire will result. Tank trucks catch fire and burn, but they seldom explode if the vents are made in accordance with the standards of the National Fire Prevention Association, the American Petroleum Institute, or the Interstate Commerce Commission and if they are kept in proper repair and free of corrosion.

Persons unfamiliar with the petroleum industry and sometimes even employees of the petroleum industry often express fear that an explosion will result from a spark in an underground tank at a filling station operating in a moderately cold climate or from a fire at the vent or opening of a tank filled or partly filled with gasoline or similar liquids. A simple experiment will show the fallacy of this fear. (See fig. 2.) The two-holed glass flask represents the underground storage tank of a filling station and the curved glass tube represents the vent pipe. The location of the vent pipe is important in any gasoline storage tank. Many stations have blown up because the vent pipe was not high enough to permit the vapors to be diluted with air before they drifted into the filling-station buildings. Strange to say, some vents have been placed inside of the buildings, certainly a very dangerous type of installation. The vents should extend well above the top of the filling station or the first floor of the building and should be placed so that the vapors will be dissipated without danger of ignition or of being blown into inhabited buildings in concentrated form.

A little gasoline is poured into the flask which represents the underground storage tank, as there is almost always some liquid gasoline in the underground storage tank of an operating filling station even though it may appear to be empty. Gasoline vaporizes at relatively low temperatures, hence the space above the liquid in a gasoline container may be filled with those vapors. To illustrate how a severe accident can occur, assume that a tank-wagon driver is delivering a load of gasoline into the underground tank. The bulb-shaped funnel in figure 2, filled with gasoline, represents the truck, the valve at the bottom of the funnel represents the valves at the back of the truck, and the tube leading from the funnel to the flask or bottle represents the hose from the truck to the underground tank. Assume also that as the gasoline flows into the underground tank, some careless motorist entering or leaving the filling station strikes a match, and the flame ignites the gasoline vapors issuing from the vent pipe. (To demonstrate this ignition the valve is opened, and as the gasoline flows into the lower bottle the vapors from the vent are ignited and allowed to burn.) There would be no need to call the fire department, as it would cost that department $25 to $50 to make a run for what might be termed a "10-cent fire." If the driver would step to the tank truck and close the valve controlling the flow of gasoline, the fire would be extinguished because the fuel supply would be stopped (as can be demonstrated by closing the valve on the gasoline container in fig. 2).

In this experiment it will be noted that the fire does not follow down the glass vent tube into the flask, because there is not enough oxygen in the tube or flask to support combustion. In other words, a long vent pipe is not needed to prevent fire from entering a gasoline storage tank; length is necessary only to carry the fumes to a safe distance. This fact may be demonstrated by removing the glass tube and cork and again allowing gasoline to flow into the container and by igniting the vapors issuing from the large opening. When the supply of fuel is shut off, the flame is extinguished.

A fire of this type occurred in which the tank-wagon driven, not knowing how to handle the fire, jumped into the tank truck and drove down the street without shutting off the gasoline. He thereby converted an essentially harmless fire into one that caused several thousand dollars worth of damage. If the receiving tank had been large enough to take all the gasoline in the compartment of the tank truck and the driver had allowed the gasoline to continue to flow, probably the fire would have been extinguished when the compartment was emptied, as can be shown with the equipment in figure 2. In conducting this experiment, the gasoline should be allowed to flow from the gasoline container into the Woulff bottle, and the vapors escaping from the curved glass tube should be ignited. When the container is empty the flame will be extinguished, as the oxygen (air) will not be carried into the lower container. In other words, the bottom leg of the triangle would be removed, the triangle would collapse, and the fire would be extinguished.

Before leaving the subject of vents, the author wishes to stress again the need for making certain that the vents are high enough for the vapors to be diluted properly in the atmosphere and are placed so that the vapors will not drift through a window or other opening of a filling station or some adjacent building. In moderate climates it is not necessary to place a screen over the mouth of the vent to prevent the flame from traveling back into the tank; on the other hand, it is desirable that the mouth of the vent should be open so the vapors will always have a means of escape.

The belief[5] is general that to have a flame or fire a jet of inflammable gas must be surrounded by air or oxygen. The experiment with the equipment shown in figure 3 gives the impression that it is possible to burn air in gas.

The apparatus comprises a lamp chimney with a small glass inlet tube for inflammable gas, a large open glass tube extending through a tight cork in the bottom of the chimney, and a flat piece of tin containing a small hole about the size of the large glass tube closing off the top of the chimney.

Inflammable gas is fed into the chimney through the small tube at the bottom until all the air is displaced. When the hole in the cover of the lamp chimney is closed, the gas may be ignited at the end of the large tube which projects from the bottom. When the hole is opened, the upward draft will cause the flame of the burning mixture to proceed slowly up the tube, and soon a flame will be seen at the end of the air tube burning in an atmosphere of pure inflammable gas; that is, air is combining with gas to burn in gas. As an excess of gas is flowing into the chimney, the gas flowing from the hole in the metal cover at the top of the chimney may also be ignited, as shown; therefore, popularly speaking, this flame represents gas burning in air.

It is not true that gas burns in air or air burns in gas, because "a flame is a phenomenon produced at the surface where two gases meet and undergo combination with the evolution of heat and, more or less, light."[6] From a chemical standpoint, therefore, it makes no difference whether the gas on the outside of the flame contains oxygen and inflammable gas is on the inside or whether the order is reversed; in other words, it is the mixture of inflammable gas and oxygen that burns, not the pure inflammable gas or the pure air (oxygen).

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[5] This equipment was not part of that used by Howell. (See footnote 4.)

[6] Smith, Alexander, General Chemistry for Colleges; The Century Co., New York, 1908, p. 337.

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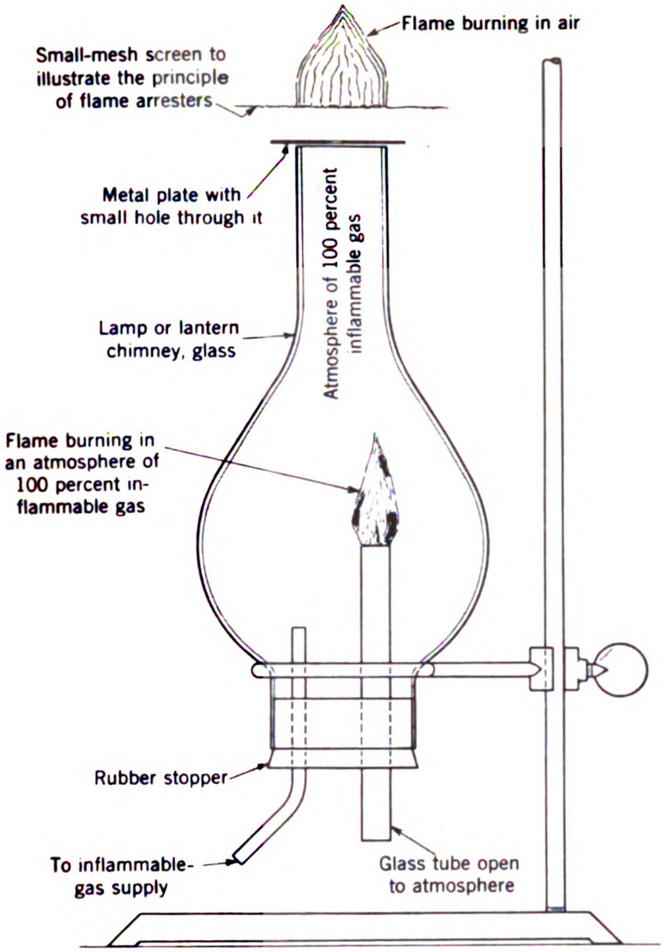
Flame burning in air
Small-mesh screen to illustrate the principle of flame arresters
Metal plate with small hole through it
Atmosphere of 100 percent inflammable gas
Lamp or lantern chimney, glass
Flame burning in an atmosphere of 100 percent inflammable gas
Rubber stopper
To inflammable-gas supply
Glass tube open to atmosphere

Figure 3.- Diagram of equipment for demonstrating that an inflammable gas-air mixture will burn in an atmosphere of 100 percent inflammable gas or air and for demonstrating the phenomenon of flame.

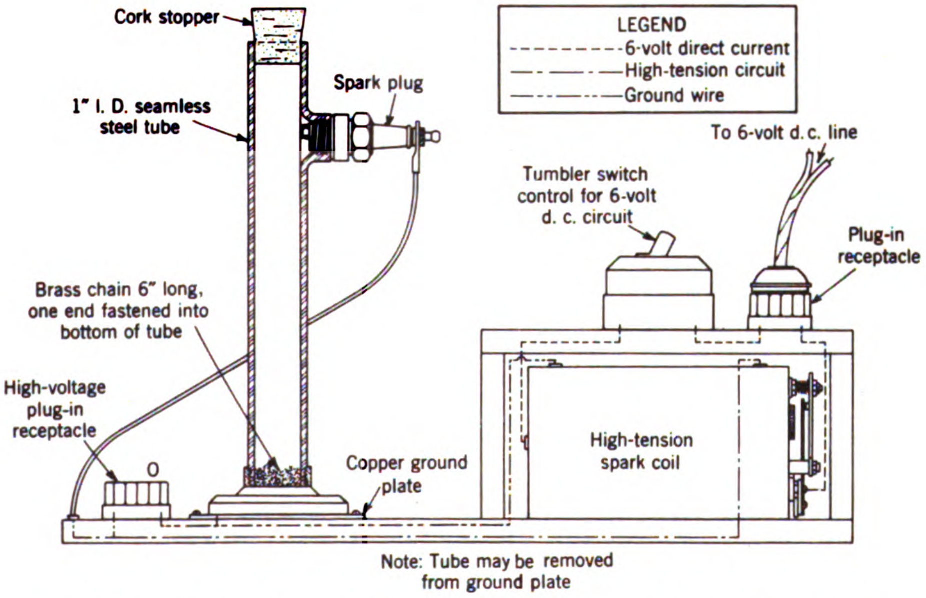
Cork stopper
LEGEND
6-volt direct current
High-tension circuit
Ground wire
Spark plug
1" I. D. seamless steel tube
To 6-volt d. c. line
Tumbler switch control for 6-volt d. c. circuit
Plug-in receptacle
Brass chain 6" long, one end fastened into bottom of tube
High-voltage plug-in receptacle
O
Copper ground plate
High-tension spark coil
Note: Tube may be removed from ground plate

Figure 4.- Diagram of equipment for demonstrating the inflammable limits of gasoline and similar vapors.

This experiment illustrates how the flame from a burning torch may be sucked back into a tank as the oil is pumped out unless some device is used, such as a flame arrester or a liquid seal.

The principle of the flame arrester can be illustrated by placing fine-mesh wire screen (approximately 28 openings to the linear inch) across the opening in the cover at the top of the chimney and igniting the gas above the screen. The screen may be held in the hand, and as it is raised slowly the flame stays above the gauze and the gas beneath it does not fire. If the wire gauze is raised higher, a point is reached at which the flame is extinguished. The wire gauze does not burn the hand or become hot immediately. The flame does not travel through the gauze, because the small wires conduct the heat away rapidly enough to prevent it from being transmitted to the gas below the gauze. This example shows how to prevent a fire or an explosion by actually removing the heat; it also illustrates the fundamental safety feature of the flame safety lamp, which is and has been used widely in coal mines.

So far only vessels that contain a volatile fluid, filled or partly filled tanks, and cans have been considered. Empty containers, that is, containers that have been filled with a volatile fluid that gives off an inflammable vapor and have been virtually emptied, will now be discussed. The ordinary gun has to be loaded before it can explode but "emptied" cans of gasoline, alcohol, turpentine, paints, and other liquids will explode when a flame or an electric arc comes in contact with them. It is the so-called empty container with its small residue that is extremely dangerous not the loaded container, which contains a liquid that vaporizes at the temperature of the container and usually is equipped with the proper safety valves.

The equipment in figure 4 can be utilized to show what occurs in an "empty" gasoline container. One or two drops of gasoline are placed in the empty steel cylinder, and the open end of the cylinder is corked. Reference to the diagram of "fire", page 5, indicates that the triangle can be completed in this steel cylinder. The air was in the cylinder before the drops were added, and the gasoline is the fuel. (To help turn the liquid into a vapor, a short length of chain is fastened to the bottom of the cylinder.) If the corked cylinder is shaken the drops will be turned into vapor quickly. Heat or flame is obtained by connecting the spark plug in the cylinder to the coil and energizing the coil. A LOUD EXPLOSION OCCURS IMMEDIATELY. This experiment shows what occurs in a so-called empty container.

A gallon of gasoline contains approximately 200,000 times as much gasoline as one of the small drops placed in the cylinder. If the noise made by the explosion of the two drops of gasoline could be amplified 100,000 times, some idea would be obtained of the tremendous amount of energy in a gallon of gasoline. When a gallon of gasoline is used in a certain manner as in a combustion engine it is said to contain the energy equivalent of 15 to 50 or 85 to 95 pounds (depending on which authority is accepted) of 40-percent straight nitroglycerin dynamite, that is, 30 to 200 sticks of dynamite.

In many homes, garages, shops, and other places gasoline is stored in glass or other unapproved containers, yet the person responsible for keeping the gasoline in such a container or location would not think of leaving even one stick of dynamite in the same place, even though a gallon of gasoline contains one to two hundred times as much energy which, when vaporized, can be released nearly as easily as the energy in the dynamite.

An irrigation tunnel 9 feet in diameter is being driven through solid rock under the Continental Divide in Colorado. The energy in 1,250 gallons of gasoline, the capacity of most tank trucks used to distribute gasoline in cities, in terms of dynamite, would blast the rock necessary to excavate this tunnel for nearly 4 miles. Nevertheless, millions of gallons of gasoline and thousands of pounds of dynamite are used and transported every day with absolute safety by obeying certain fundamental rules. It is claimed that the vapor produced by a cup of gasoline blew up nearly a block of sewer line in Chicago.

The experiment conducted in the equipment shown in figure 4 illustrates what 1 or 2 drops of gasoline will do when ignited in a confined space, such as a so-called empty gasoline tank or other container. It is also desirable to determine what 6 or 7 drops of gasoline will do when placed in the container and properly sealed and shaken; when the spark is formed in the sealed cylinder no explosion occurs, yet fuel is present in the form of vapor, as well as air and heat. If the cork is removed and some of the invisible gasoline vapors, which are heavier than air, are poured from the container and if it is again corked and shaken and a spark formed inside of the container, an explosion will occur.

It might appear that the "fire" triangle is in error; it is not, but the elements making up the triangle must be within well-defined limits. The amounts of inflammable gas and air must bear a definite relation to each other, and the heat present must be above a certain temperature. If there is too much or too little air or gas an explosion will not occur. It is impossible to have too much heat, but there can be too little heat, as will be indicated later in this paper. This experiment explains why gas engines are sometimes hard to start in the field.

So far, the following essentials for a fire have been indicated: (1) Fuel must be present; (2) air must be present; (3) enough heat must be present to ignite the mixture (this will be discussed later); and (4) the proportions of fuel and air must be within well-defined limits. It has been shown also that gasoline vapors are heavier than air and may be poured from a vessel.

The following experiment further confirms these facts. A sheet-metal trough about 6 feet long and 4 inches on the sides and bottom is placed so that one end is approximately 2 feet higher than the other end. A short piece of candle is lighted and placed at the bottom of the trough, and a wad of cotton that has been nearly saturated with gasoline is placed at the top of the trough. (Care should be taken that no liquid runs from the cotton down the trough.) If no heavy air currents are present, the gasoline vapors given off by the wet cotton will drift down the trough, be ignited by the candle, and flash back to the cotton. This fact explains in part why it is dangerous to use gasoline for cleaning around the home or on the job, or to wash the hands or clothes that are being worn with gasoline or other liquid that vaporizes at ordinary room temperatures.

Frequently, vapors from crude oil, leaking gas lines, and industrial plants outside of the petroleum industry have drifted or been wafted by gentle air currents considerable distances and have been ignited and flashed back to their source. A man in East Texas states that he witnessed a cloud of vapor which drifted nearly 2 miles down a draw and was ignited at a boiler, the flame traveling back to the source.

Many men, women, and children have been seriously or fatally burned at home because the vapor from a pan of gasoline being used to clean clothes or to fill a lamp or stove, was ignited when it drifted to the flame of a water heater or even downstairs to the flame of a furnace; in the open, the vapor may drift to an automobile that has just been driven up. Enough static electricity to ignite gasoline vapors may be generated by rubbing certain materials together; many persons have been burned in their homes because they were using inflammable liquids that were ignited by friction, by static sparks or arcs, or by some other means.

Gasoline should not be used for cleaning around the home or on the job. Safe cleaning fluids can be obtained at drug stores and at many filling stations and should be used. Gasoline should not be used to clean tools, machinery, and other equipment on the job. Many persons have been burned when they spilled a little gasoline on their clothes or bodies or used gasoline to remove grease spots from their clothes, then walked past a gas or electric heater, electric motor, or other source of heat; probably no injury is more painful than a burn.

In some industries, including the petroleum industry, it is desirable or even necessary to determine whether an atmosphere is inflammable before allowing men to work in it. Several accurate instruments are available for detecting the presence of inflammable vapors. Recently developed indicators are based upon the principle that when a heated electric filament is introduced into an inflammable gas the electrical resistance of that filament is increased in direct proportion to the amount of inflammable gas present between zero and the lower inflammable limits of the gas. The utility of such an instrument may be demonstrated by using the trough previously described and replacing the candle by the gas-detecting device or some part of it.

The intake tube of the inflammable-gas detector is placed at the bottom of the trough, and the aspirator bulb or pump is operated so that it sucks the vapors from the bottom of the trough into the instrument and over the heated filament. The needle indicates when the mixture of gasoline vapors is explosive, by moving to a point above the top of the scale. If a lighted match is held at the intake tube the vapors will be ignited and will flash back to the cotton.

It is often important to know in what direction and to what point the various vapors are going. This information may be obtained in several ways. Many safety and ventilation engineers use glass smoke tubes sealed at each end and containing ground pumice saturated with stannic chloride or fuming sulfuric acid; these tubes are obtainable in the open market. The ends of the tube are broken, and one end is inserted in the exhaust side of an aspirating bulb; if air is blown through the tube by squeezing the bulb, a dense white smoke is emitted that remains suspended in the air for a considerable time and travels with the air currents.

If a ball of cotton wet with gasoline is placed at the top of the trough and a lighted candle at the bottom and if the fumes from the smoke tube are ejected into the trough just below the cotton, then the smoke will flow down the trough and pass over the flame of the burning candle, along with the inflammable vapor that is ignited by the candle flame.

Extinguishing Fires

The preceding experiments show that removing the fuel supply, the oxygen (air) supply, or the heat will extinguish the fire. Water is used ordinarily for extinguishing fires. Although water should not be used to fight most oil fires, it is very effective on some oil fires when employed in the form of a fine mist or fog and handled properly. The mist helps to exclude the air and, when in contact with the fire, turns to steam which further aids in excluding the air; also it tends to cool the burning substance.

The following information is given to point out the hazards of extinguishers, not to condemn any type that is sold and used in accordance with recommended practices, as there is a place for every extinguisher of approved type. No one type is likely to prove effective on all fires any more than one medicine is likely to cure all diseases. To evaluate the safety and effectiveness of various fire extinguishers, the Underwriters' Laboratories, Inc.,[1] divide fires into the following three classes and indicate the suitable type of extinguisher to use:

CLASS A FIRES are defined as incipient fires on which the quenching and cooling effect of quantities of water is of first importance, i.e., incipient fires in ordinary combustible materials, such as wood, paper, textiles, rubbish, etc.

CLASS B FIRES are defined as incipient fires on which the blanketing or smothering effect of the extinguishing agent is of first importance, i.e., fires in small quantities of rapidly burning material, such as gasoline, oils, or greases in vats or other open vessels or on floors.

CLASS C FIRES are defined as incipient fires in electrical equipment where the use of a nonconducting extinguishing medium is of great importance.

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[1] Underwriters' Laboratories, Inc., List of Inspected Fire Protection Equipment and Materials; January 1939, pp. 38-39.

This classification is shown, opposite the following headings, in the form A-1, A-2, or A-1, B-1, etc., as the case may be. The letters A, B, or C designate the class or classes of fires on which the device is suitable. The figures following designate the number of devices required to make one unit of first-aid hand fire protection.

Experience has shown that charges for various types of first-aid fire extinguishers should be those furnished by the manufacturer of the device who cannot be expected otherwise to be responsible for unsatisfactory condition or operation.

Prospective users should first ascertain from authorities having jurisdiction under what conditions the various extinguishers will be accepted and should make contracts subject to approval by them of setting, distributing, and number to be used in respect to floor areas and other conditions.

Some authorities give a fourth class of fire that includes fires in automobiles, internal-combustion motors, motorboats, and similar equipment.

For the use of volatile-liquid and carbon-dioxide-type extinguishers, the Underwriters' Laboratories, Inc.,[8] recommend the following apparatus:

Vaporizing liquid extinguishers are first-aid fire appliances utilizing as extinguishing agent a specially treated vaporizing, nonconducting liquid (carbon-tetrachloride base) with important components for depressing freezing point, avoiding corrosion, etc., such liquids being supplied by manufacturers for use in their extinguishers. These extinguishers must be partially discharged and refilled yearly. In using extinguishers of this type, especially in unventilated spaces, such as small rooms, closets, or confined spaces, operators and others should take precautions to avoid the effects which may be caused by breathing the vapors or gases liberated or produced. Extinguishers made of brass unless otherwise listed.

The 1-qt. size (classification B-2, C-2) is especially adapted for automobile and motorboat use. It can be handled readily by women.

The 1-1/4, 1-1/2, and 2-qt. sizes (classification B-2, C-2) are intended for use largely in industrial establishments.

The 1-gal. and larger sizes (classification B-2, C-1) are especially intended for use in electrical power stations and the like and for special industrial conditions where consideration has been given to large quantity of liquid and where such devices are usually operated by men familiar with their use, and where efficient supervision prevails.

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[8] See footnote 7.

Carbon dioxide is a nonconductor, and its properties are such that when air is displaced by it or mixed with it in suitable proportions it is effective on classes B and C fires.

In using extinguishers of this type, especially in unventilated places such as small rooms, closets, or confined spaces, operators and others should take precautions to avoid the effects which may be caused by breathing the vapors or gases liberated or produced.

Extinguishers utilize CO_2 stored in ICC-3 shipping containers which are equipped with special cutter or seated-type valves permitting release of CO_2 gas through hand hose and nozzle.

The small sizes are provided with a handle or strap for portability and a wall hook for mounting, whereas the large sizes are mounted on two-wheel trucks. Cylinders in service should be weighed annually to detect loss of liquid by leakage, tampering, or use.

Carbon tetrachloride extinguishers have been very popular; however, the use of this liquid on a fire in a confined space is hazardous, unless the user fully understands the action of the liquids, because when carbon tetrachloride is heated it breaks up and releases several gases, including phosgene, chlorine, carbon-monoxide, and carbon dioxide.[9] The first two gases were used extensively during the World War. The following chemical formulas[10] show how carbon tetrachloride liquid breaks up into gases when sprayed on a fire or heated substance:

CCl_4 (Carbon tetrachloride)	+	H_2O (Water)	=	$COCl_2$ (Phosgene)	+	$2HCl$ (Hydrochloric acid)
$2CCl_4$ (Carbon tetrachloride)	+	O_2 (Oxygen)	=	$2COCl_2$ (Phosgene)	+	$2Cl_2$ (Chlorine)
$3CCl_4$ (Carbon tetrachloride)	+	Fe_2O_3 (Ferric oxide)	=	$3COCl_2$ (Phosgene)	+	$2FeCl_3$ (Iron perchloride)
$2CCl_4$ (Carbon tetrachloride)	+	Heat	=	C_2Cl_4 (Tetrachlor-ethylene)	+	$2Cl_2$ (Chlorine)
CCL_4 (Carbon tetrachloride)	+	$2H_2O$ (Water)	=	CC_2 (Carbon dioxide)		$4HCl$ (Hydrochloric acid)

The quantity of these gases generated in a fire depends on the amount of carbon tetrachloride required to extinguish the fire. The physiological effect of breathing the gases depends on the concentration of gas or gases in the atmosphere, the length of exposure to them, and the physical condition of the person breathing them. A person forced to breath air containing

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[9] Fieldner, A. C., and Katz, S. H., Gases Produced in the Use of Carbon Tetrachloride and Foamite Fire Extinguishers in Mines: Bureau of Mines Rept. of Investigations 2262, 1921, pp. 2-4.
Katz, S. H., Gleim, E. J., and Bloomfield, J. J., Carbon Tetrachloride Extinguisher on Electric Fires: Bureau of Mines Rept. of Investigations 2499, 1923, p. 6.

[10] Chemists of the American-LaFrance-Foamite Corporation, Elmira, N. Y. and the Bureau of Mines.

0.009 percent of phosgene by volume or 0.09 percent of chlorine will be killed in a short time.[11] Breathing air containing 0.2 to 0.25 percent of carbon monoxide may cause death in 30 minutes to 2 hours, and 10 percent of carbon dioxide in air may produce serious symptoms almost immediately.[12] Other gases likely to be generated when carbon tetrachloride extinguishers are used on a fire are hydrochloric acid gas, tetrachlorethylene, and carbon tetrachloride vapors, in addition to the gases that would be generated by the burning substances if no carbon tetrachloride were applied. Therefore, extreme care should be taken to insure that any person who uses a carbon tetrachloride extinguisher does not inhale the fumes. The printed warning on many carbon tetrachloride-type extinguishers states: "AVOID INHALING THE FUMES." The Underwriters' Laboratories, Inc.,[13] give the following data on the use of volatile-liquid extinguishers:

> Extinguishing effect of the liquid is due primarily to the smothering action of the heavy blanket of vapor developed by the heat of the fire. One quart of liquid produces about 10 cubic feet of vapor. The liquid has little cooling effect, due to its low specific heat and low heat of vaporization. It is a nonconductor of electricity. It is effective on small flammable liquid or grease fires (class B) and fires involving electrical equipment (class C). Compared to foam on class B fires, the vapor blanket is impermanent, and it is possible for reflashes to occur over the entire area if the fire was not fully extinguished.
>
> Classification: Regardless of size, hand-vaporizing liquid extinguishers carry maximum classifications of B-2, C-1, and are not recommended for class B fires of more than 6 sq. ft. in area. They should not be applied to fires involving sulphuric acid. They are relatively ineffective on fires involving deep-seated embers but may be of value on small surface fires involving wood, paper, textile materials, rubbish, etc.

If carbon tetrachloride is used on a fire the liquid should be sprayed from the windward side through a window, door, or other opening. For example, a person should not enter an automobile and spray the liquid onto a burning cushion. The tremendously irritating effects and the odor of the fumes from carbon tetrachloride can be demonstrated by placing 2 teaspoonfuls of gasoline into a small-diameter shallow pan and igniting the vapors. A relatively small quantity of smoke is given off by the burning vapors, but if 1 teaspoonful of carbon tetrachloride is added the fumes and smoke become dense (DO NOT take a deep breath of these fumes). A second, or perhaps a third, spoonful of carbon tetrachloride must be added to the pan of burning gasoline before the flames are extinguished.

11/ Sayers, R. R., and DallaValle, J. M., Prevention of Occupational Diseases Other Than Those That Are Caused by Toxic Dust: Mech. Eng., vol. 57, No. 4, 1935, pp. 230-234.

12/ Bureau of Mines, Manual of First-Aid Instruction: 1940, pp. 61-62.

13/ Underwriters' Laboratories, Inc., Card Data Service, Serial No. UL165, June 1939.

It is claimed that the irritating gases generated by the use of volatile-liquid extinguishers will force a person to leave the fire area; they may drive him out just when a little more work might have extinguished the flame. If the user has been warned previously that irritating vapors will be produced, he can take the necessary precautions before attempting to extinguish the fires.

This experiment does not indicate the amount of carbon tetrachloride necessary to extinguish a gasoline fire; a much smaller amount would be effective if it were applied properly by spraying. As stated, it is the noninflammable vapors, not the liquid, that extinguishes the fire. The amount used in the experiment indicates the quantity that might be necessary to make a given quantity of gasoline liquid noninflammable, which is the usual method of making cleaning solvents safe. The experiment should not be continued in a small room for any length of time without ventilating the room, otherwise the fumes generated may be irritating or may cause illness.

All safety engineers and fire departments desire that each person should understand fully what he is doing when he is using a fire extinguisher that may cause the formation of gases of a toxic nature or may be employed on an electric fire.

Fire extinguishers containing carbon dioxide gas under pressure are becoming popular and are recommended for class B and C fires. Carbon dioxide is a noninflammable gas weighing 1-1/2 times as much as air, therefore it will tend to hang in a cloud close to the ground or other low place and, when applied from the windward side at the base of a flame, will smother a fire by excluding the air in essentially the same manner as if a wet blanket had been used. Air containing more than 10 percent carbon dioxide can be breathed only a short time.

Several carbon dioxide fire extinguishers are on the market. In some plants large banks of cylinders are arranged to flood a machine room or area automatically with carbon dioxide when a fire occurs. As carbon dioxide dilutes the oxygen in the air or may even exclude it, extreme care must be taken that enough oxygen is present to support life before entering a room where a fire has occurred or where carbon dioxide has been used to extinguish the blaze. (The use of a carbon dioxide-type extinguisher on the cotton fire can be demonstrated with the trough, keeping one 5-pound and one 15-pound extinguisher with the exhibit at all times to take care of any fire emergency that might arise in connection with the experiment.)

Regardless of the type of agent used to extinguish a fire in a confined area, no person should enter the area without proper respiratory protection, unless it has been thoroughly ventilated. Canister-type gas masks do not give adequate protection against an atmosphere containing more than 2 percent of most gases and give no protection whatsoever against an atmosphere deficient in oxygen; this fact is important, as numerous persons have lost their lives by wearing canister-type gas masks when fighting fires.

Small fires about the home, such as those in small pans of burning grease, and small gasoline, oil, and automobile fires can be extinguished with ordinary baking soda (bicarbonate of soda) by sprinkling the soda over the small pan or blaze. WARNING: Do not use flour, as flour dust is inflammable and under some conditions explosive. Although salt may extinguish a small fire, it contains water, which may cause the grease or oil to splash, hence should be used with caution.

The effectiveness of bicarbonate of soda can be demonstrated by placing a small quantity of gasoline in a frying pan (a glass frying pan is preferred) about 6 inches in diameter, igniting the gasoline, and sprinkling bicarbonate of soda into the pan until the flame is extinguished. The quantity necessary to extinguish the blaze depends upon how it is applied; 1 to 2 tablespoonfuls generally suffices.

A combination of sodium bicarbonate with certain compounds and carbon dioxide gas under pressure in a fire extinguisher has proved effective on many gas and oil fires. It is sold under a familiar trade name. In an extinguisher of this type sodium bicarbonate is treated with a compound to prevent caking. The extinguisher excludes air from the fire and insulates one layer of inflammable gas, thus preventing the heat from being conducted to the next layer. In the presence of heat bicarbonate of soda releases carbon dioxide gas, which also assists in extinguishing the fire. The Underwriters' Laboratories, Inc., give the following description of the scope of this extinguisher:[14]

> Scope: This discharge of the powder compound is effective in class B and C situations, where the dust cloud may dilute air adjacent to the seat of the fire or separate the flames from the burning material. It is especially effective on flat surface fires where the sweeping action of the dust cloud can be most advantageously employed. While little practical cooling action is provided by the dry powder, the extinguishers may be of value on surface fires involving paper, wood, textiles, etc. They are not effective on deep-seated fires or embers.
>
> The powder cloud is transient in its extinguishing action and does not form a blanket, as in the case of foam, on class B fires, thus permitting reflashes over the entire area if the fire has not been completely extinguished. It is, however, equally effective on oil or alcohol types of flammable liquid fires.

For many years fire extinguishers that generate foam have been used for extinguishing oil fires and have been effective when the foam was applied correctly. Fire extinguishers of this type contain two liquids; one may be dark brown and the other white or clear, or both may be white or clear, depending on the manufacturer. The liquids are kept in separate containers and allowed to mix only at a point close to the blaze, because the foam that is generated by mixing the solutions will break up if forced through a hose or pipe of any length. One manufacturer uses a solution of water, sodium bicarbonate, and secondary extract of licorice root with a solution of aluminum sulfate and water. Some manufacturers use ground glue and glucose instead of the licorice-root extract to make the bubbles tough. (The chemical reaction[15] involved in generating the foam is $Al_2(SO_4)_3 + 6NaHCO_3 = 3Na_2SO_4 + 2Al(OH)_3 + 6CO_2$, and the carbon dioxide is trapped in liquid bubbles.)

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[14] See footnote 13.

A few years ago a large tank of oil on the Pacific coast ignited and enough foam was pumped into the tank to fill it several times without extinguishing the fire. To determine the reason for the failure of the foam, several oil companies rebuilt the tank and conducted numerous experiments. It was found that as the foam dropped from the mixing chamber into the flaming oil it was broken up in such a manner that only a small quantity spread over the surface of the oil. After much experimentation a tube of reinforced asbestos was fastened to the end of a gooseneck, which was long enough to reach above the top of the tank. When a fire occurs in an oil tank the gooseneck is wheeled to the windward side and raised so the asbestos tube can be dropped inside the tank. The solutions are pumped into the gooseneck and generate foam which flows through the asbestos tube that is probably submerged in the oil. The tube then rises to the surface of the burning oil, and a blanket of the foam spreads over the surface, extinguishing the fire. One manufacturer of fire equipment has placed on the market spiral chutes that may be fastened on the inside of the tank to conduct the foam from the mixing chambers at the top of the tank to the surface of the burning oil without breaking it up.

The instructions that are given for the use of foam extinguishers of any type state that the foam should not be directed into the burning liquid but should be applied so as to spread over the surface in the form of a blanket.

ELECTRIC FIRES

The first essential in a fire in or around electric equipment is generally to cut off the source of electric energy. (This fact indicates the desirability of proper openings or switches in all power lines so that electric current can be disconnected with minimum delay.) Although certain extinguishing substances may quench the electric arc, the arc will generally reform when the substance is removed, unless the power is cut off.

As stated, carbon tetrachloride, carbon dioxide, and some combinations of sodium bicarbonate and carbon dioxide are approved by the Underwriters' Laboratories, Inc., for use on electric fires.

When properly handled by experienced men, a fog of water can be applied safely to electric fires, although this technique is risky for the amateur.

It is stressed again that unventilated fire areas should not be entered even when no fire extinguisher has been used, unless the proper type of respiratory protective equipment is worn, and it should be remembered that a canister-type gas mask affords little or no protection.

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[15] Fieldner, A. C., and Katz, S. H., Gases Produced in the Use of Carbon Tetrachloride and Foamite Fire Extinguishers in Mines: Bureau of Mines Rept. of Investigations 2262, 1921, 6 pp.

EXPLOSIONS

A brief discussion of the explosion disaster at the New London School, New London, Tex., may assist not only in preventing similar disasters but also in explaining why many explosions occur in the petroleum industry. Moreover, it should help to explain the construction of electric equipment that bears the permissible plate of approval of the Bureau of Mines or the approval plate of the Underwriters' Laboratories, Inc.

Although it is impossible to state exactly what has caused many explosions, competent investigators usually are able, after the proper investigation, to determine the probable cause and source of the material that has burned or exploded, as well as the igniting agent.

Immediately after the New London School disaster, some engineers of the Federal Bureau of Mines, among other experts, made a detailed investigation, and the results of this investigation were published in Bureau of Mines Report of Investigations 3365. This report contains information of a scientific nature and probably has saved petroleum companies and parents whose children were killed in the explosion many thousands of dollars in useless and expensive lawsuits, because the work done by the Bureau engineers showed that gas did not seep into the building from nearby wells, gas lines, or storage tanks. The report states: 16/

> The investigation revealed that the explosion was not caused by high explosives, seepage of hydrocarbon vapors or liquids from nearby oil wells or pipe lines into the space under the first floor, or combustibles from the sewage system; therefore, by a process of elimination the source of combustibles appeared to be natural gas supplied as fuel to the school through lines and services installed in the space under the floor.
>
> The only evidence contradictory to the general conclusion that the explosion was due to an accumulation of highly explosive natural gas-air mixture in the space under the first floor was given by a janitor at the school, who stated that he entered the space through the door at the south end on the morning preceding the explosion and struck a match. No explosion resulted when the match was ignited, and the janitor did not observe any unusual condition.
>
> This evidence indicates that at one spot in the south end of the space under the floor natural gas was not present in explosive proportions a few hours before the explosion. However, it is not at all certain that appreciable percentages of natural gas were not present there also. There are numerous oil wells and pipe lines in this district, and the air is permeated with hydrocarbon odors much of the time; therefore, the presence of natural gas in the space, in proportions below the lower explosive limit, might not have been detected.

16/ Parker, D. J., Jones, G. W., Hill, H. B., and Wade, Gustav, Explosion in School Building at New London, Tex., March 18, 1937: Bureau of Mines Rept. of Investigations 3365, 1938, 29 pp.

Mixtures below the lower explosive limit that do not contain enough natural gas to cause explosions would cause a lighted match to burn with a longer flame, but the janitor may not have noticed this, or, if he did, he probably was not aware of its significance.

The fact that explosive mixtures were not present in the south end does not contradict the general conclusion that natural gas caused the explosion, because evidence indicates that the highest concentration of natural gas was at or near the north end and near the place where the explosive mixture was ignited.***

The floor plan of the building was laid out in the form of the letter E, with the back of the letter forming the front of the building and facing west.***

The natural ground level was higher at the front of the building and sloped downward toward the rear. When the two wings were added, classrooms were provided at the rear of the unexcavated space, and the floors in these rooms were placed on the earth with no unventilated spaces underneath.

***The consensus of opinion of those who were present was that when the explosion occurred the floor, ceiling, and roof at the north end of the building were lifted upward; the walls were pushed outward, and when the force of the blast was spent the floor, ceiling, and roof fell in a tangled mass. Toward the south end there was evidence of greater violence.

When an explosive mixture of gas and air is ignited, the rapid chemical reaction that takes place heats the products of combustion to a very high temperature. As a result, if the gases are not confined they expand instantaneously to 3 to 6 times their original volume, and if they are confined their pressure is increased with like rapidity. When such an explosion of a natural gas-air mixture, initially at atmospheric pressure, takes place in a space where there is no opening, the pressure developed, measured in atmospheres, is approximately equal to the ratio of the highest absolute temperature of the products of combustion to the initial temperature of the gas mixture. If the pressure within the space exceeds the ability of the walls to resist it, the chamber is ruptured and the heated gases travel from the high-pressure area to the outside atmosphere along paths of lower resistance and pressure. Therefore, damage resulting from an explosion in a chamber whose walls offer considerable resistance is not localized, but may extend over an area much greater than that in which the explosive mixture was present originally. The more rugged the walls and the smaller the areas of the openings in them, the higher will be the pressure at which the chamber is ruptured and the greater the resulting damage.

The explosion originated under the first floor and covered the entire space that extended from the north end and along the front of the building to the south end. This conclusion was reached after a study of the visual damage to foundation walls and the evidence obtained from various witnesses, who described the directions of the force of the explosion.

> The plans show that the space under the first floor had four small ventilators 11 by 22 inches in size (one at the north end, one at the south end, and two on the east side) and two doors, each 4 by 4 feet. The door at the south end was said to have been closed. According to information, the door at the north end, opening into the manual-training room was usually left open because some of the lumber used in the manual-training room was stored just inside the door. This doorway was in the wall separating the manual-training shop from the space under the floor of the main building, and its bottom edge was about 4 feet above the floor level of the shop.
>
> From a practical standpoint, the space below the floor was a closed chamber; no ventilation was provided in the west wall of the building, which was 254 feet 11 inches over all, in length, and the four ventilators (two in the east wall and one each in the north and south walls) did not allow enough natural draft to ventilate a chamber of this volume and shape. The reinforced concrete foundation walls and floor were poured as a unit and formed a tight barrier against the release of pressure generated by the explosion, until the pressure reached sufficient magnitude to rupture the foundation walls and burst the floor.

Witnesses testified that the ignition of gas took place when the electric sander was started in the manual-training room. It may seem strange that a person could witness such a forceful explosion and live to tell about it. In investigating explosions in coal mines and other places, Bureau of Mines engineers often are able to trace the source of ignition, because at that point there usually is less force or evidence of force than at distant points. If an ignition takes place at one end of a long room, such as an auditorium, which is more or less filled with an explosive mixture of gas, by the time the explosion has reached the other end of the room it will probably have built up a much greater pressure than it had at the beginning, simply because additional quantities of gas have been heated and expanded; undoubtedly this was what happened at the New London School.

Fires and explosions caused by ignition of inflammable vapors by an electric arc are not as common in the petroleum industry as they have been in the past; however, they still occur and are caused by the use of unapproved or nonpermissible or open types of electric equipment.

Records are not available of the fires caused by electric arcs in the petroleum industry; however, during the past 10 years electricity is known to have been the igniting agent in 110 explosions that killed 573 men in the coal mines of the United States.[17]

To illustrate various sources of ignition of explosive gas by electric equipment, Bureau of Mines engineers have designed a small portable explosion chamber composed of a heavy glass cylinder approximately 7 inches in inside diameter and 12 inches long. This hollow glass cylinder is clamped between two metal plates that have openings approximately 6 inches in diameter and is mounted vertically on a square, hollow, wooden base. The opening in the bottom plate is designed so that various plates containing different electric devices can be clamped in the cylinder in this opening and electric connections made. The opening in the top plate is equipped with a metal ring so that a thin piece of paper may be clamped over the opening. Thus, electric equipment may be sealed inside the glass cylinder. By means of a small plunger-type hand pump (which can be filled to a predetermined point with inflammable gas from a high-pressure steel cylinder), a measured quantity of natural gas can be forced into the glass cylinder through small openings in the metal plates which are connected to the pump cylinder. (This chamber is in part a small replica of the large testing tank of the Federal Bureau of Mines at Pittsburgh, Pa.)

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[17] Harrington, D., and Fene, W. J., Coal-Mine Explosions and Coal- and Metal-Mine Fires in the United States During the Fiscal Year Ended June 30, 1938: Bureau of Mines Inf. Circ. 7048, 1939, 21 pp.

A small (0.01 horsepower) electric motor using carbon brushes can be placed inside of this chamber and sealed. When the current is turned on, the arc from the brushes ignites the inflammable gas mixture in the glass cylinder, generating pressure which is released by rupturing of the paper diaphragm.

The motors used in the field to set up the bolts on tanks, for drill holes, and for innumerable other uses are much more powerful, and if they are equipped with open brushes or unapproved-type switches, controllers, or cables are likely to cause an arc that will ignite gas as readily as the smaller motor used in this experiment.

The demonstration motor is designed so that by screwing a metal plate over the opening leading to the brushes it will have essentially the features of a standard approved or permissible motor for emergency use in an inflammable mixture of gas. When the plate is screwed onto the back of the demonstration motor, thereby making it enclosed or "permissible," and the motor is placed inside of the chamber filled with an explosive mixture of gas and air, it can be operated at full speed, even started and stopped, without igniting the inflammable-gas mixture around it. The safety of approved or permissible electric equipment, other than portable hand lamps, depends on enclosing the brushes and arcing parts in a case strong enough to withstand any explosion that might occur on the inside and on having all openings leading into the case so small and of such length that the flame or gases escaping from an inside explosion will be cooled to a temperature below that required to ignite gases on the outside. All permissible electric equipment, other than portable electric lamps, have large openings sealed with plates that have milled bearing surfaces, and no gaskets are permitted to be used, except where the threaded surface will accomplish the same purpose as the milled surface; gaskets are not permitted because they may blow out and hence leave openings through which flame or highly heated gases may escape, thus igniting gases in the atmosphere surrounding the equipment. The area between the shaft and the bearings must be of a definite dimension and design known to prevent escape of flames or highly heated air or gases and the cables leading into the casing must be packed heavily with specified packing. No long or large spaces are permitted in the casings; thus excessive pressures are avoided if an explosion occurs within the case.[18]

Permissible electric equipment is NOT VAPORPROOF, and it is believed that no piece of electric equipment on the market is vaporproof. So-called "vaporproof fixtures" are neither vaporproof nor explosionproof; however, electric equipment of essentially all types is made explosionproof, and such equipment generally bears the approval either of the Underwriters' Laboratories, Inc., or the Bureau of Mines.

With changes in temperature or barometric pressure, every piece of electric equipment is likely to "breathe" in or out; thus it is possible for a mixture of inflammable gas to accumulate within a piece of electric equipment. If an arc occurs in such a mixture an explosion will take place, but if the equipment is made and maintained in a "permissible" manner the flame cannot be transmitted to the atmosphere surrounding the equipment. In the Bureau of Mines method of testing electric equipment for permissibility, holes are drilled in the cases of the motor, controller, switches, and other arcing devices of the machine tested so that these parts can be filled with an explosive mixture of natural gas. The holes are plugged, and the equipment is placed in a large chamber filled with an explosive mixture of the same gas. A spark plug in the case ignites the gas inside, and if during 10 or more tests the case ruptures or permits flame to travel to the outside and ignite the outside explosive mixture, of if an excessive pressure is noted, the equipment is not approved.

Bureau of Mines engineers do not know of a single ignition of an inflammable atmosphere of gas and air by a piece of permissible electric equipment that was being used and maintained properly; however, equipment that has been approved by the Bureau of Mines or Underwriters' Laboratories, Inc., has caused explosions when NOT PROPERLY MAINTAINED AND USED. Only when approved or permissible electric equipment is maintained in the same condition that it was when received from the manufacturer, except for ordinary but not excessive wear, can either of these organizations guarantee that it may not cause ignitions, hence it is imperative that approved or permissible equipment be kept in the best possible repair, that all parts be fully assembled and fastened in place, and that the equipment be operated with utmost care.

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[18] For the construction of permissible equipment, see the following Bureau of Mines publications: Illsley, L. C., and Gleim, E. J., Suggestions for the Design of Electrical Accessories for Permissible Mining Equipment: Bull. 258, 1926, 47 pp.; Clark, H. H., Permissible Explosion-Proof Electric Motors for Mines, Conditions and Requirements for Test and Approval; Tech. Paper 101, 1915, 17 pp.
Safety engineers and electricians who are interested in making inspections of such equipment are referred to Gleim, E. J., and Freeman, H. B., Maintenance of Electrical Mine Equipment from the Viewpoint of the Safety Inspector; Bureau of Mines Tech. Paper 537, 1932, 22 pp.

Many fires and explosions have occurred in the petroleum industry because of poor installation of electric wires. The wiring hazard around derricks in certain parts of the country is a discredit to the industry; power lines at many refineries, gasoline plants, bulk stations, and other operations have been strung where they could become enveloped in a could of inflammable gas or vapor in such a manner that if an arc should occur a serious fire or explosion might result. At a derrick in California a few years ago, a serious fire resulted then the joint of a drill pipe was broken and the oil splashed onto a so-called vaporproof globe that enclosed a 200-watt, 110-volt, lighted bulb; the cold oil caused the heavy glass globe and bulb to break, and an ignition occurred.

It is reported that a refinery truck accidentally backed against a power-line pole; although no damage was done to the pole or the truck, the jar caused the wires to swing and form an arc which ignited a cloud of gas. A somewhat similar ignition was reported in connection with a gas-pipe-line repair job.

Poor insulation on drop cords and other defects in wiring have been responsible for the electrocution of many workmen and for the electric arcs that have started many oil fires.

The Bureau of Mines demonstration chamber is supplied with a base on which are fastened two vertical wires that may be made to swing together and form an electric arc when sealed inside of the chamber containing the explosive mixture of gas. The wires barely touch before the arc is formed and an explosion occurs.

Many explosions and fires have occurred because an electric arc formed when a workman changed a fuse with a load on the line or changed an electric-light globe in inflammable gas or vapor without first opening the circuit.

The Bureau of Mines demonstration chamber is equipped with a base containing a safety-type cartridge fuse that may be made to form an arc when it is inserted and removed from contact with the electric current. (The safety feature of the fuse is that it "burns out" without emitting flame from the cartridge.) When the fuse is sealed in the chamber in an inflammable atmosphere of natural gas and air and the voltage and load on the line are reduced to very small quantities, the contact ends of the fuse can be made to arc without igniting the gas, because insufficient heat is generated by the spark; however, when the load and voltage are increased to normal amounts and an arc is formed, ignition occurs immediately. This experiment explains why some persons have "gotten away" with dangerous practices involving electric equipment and natural gas and stresses the fact that conditions must be "just right" before an explosion can occur. No one knows just how much the load may be on an electric line, nor can anyone tell readily just what may be the ignition temperature of the particular gas that is present.

Every inflammable mixture has a definite ignition temperature, and ignition will not take place until that temperature is reached. The main constituent of natural gas is methane; in air it has an ignition temperature of 1,260° to 1,380° F., whereas some gasoline vapors may have an ignition temperature as low as 570° F., as was proved in part by the demonstration with the fuse. If Pittsburgh natural gas is used in the demonstration chamber it can be shown that some gas mixtures are not ignited at relatively low temperatures but are readily ignited at temperatures only slightly higher. When a plate to which is attached the filament from a common electric iron is sealed in an inflammable mixture and the filament heated to a red color (a temperature between 800° and 900° F.), ignition will not take place. If the length of the filament is reduced, the electric current will heat the filament to a white heat (temperature well over 1,200° F.), and a violent explosion will occur. This demonstration proves that an inflammable mixture requires a certain amount of heat to cause ignition and that ignition does not occur until that amount of heat is applied or reached.

During February 1939 two fires that resulted in one fatality and one serious injury occurred when nonpermissible or unapproved electric hand lamps ignited an inflammable atmosphere in which men were working. The ordinary flashlight or hand lamp is not safe for use in an inflammable atmosphere unless it is constructed according to specifications similar to those required for an approval by the Bureau of Mines or the Underwriters' Laboratories, Inc.

The requirements that must be met for hand and cap lamps to pass permissibility tests are as follows:[19]

> Unless properly designed, electric cap lamps may present two sources of probable explosion hazards: (1) Ignition of an explosive atmosphere by the heated filament of the bulb in case the bulb glass is accidentally broken, and (2) ignition by sparks or flashes from the battery. The Bureau therefore requires the following safeguards:
>
> (a) Safety device (design). - The headpiece shall be provided with a safety device which shall prevent the ignition of explosive mixtures of methane and air by ejecting the bulb or otherwise removing the exposed heating filament from the circuit when the bulb glass surrounding the filament is broken.
>
> (b) Safety device (protection). - The design of the safety device and the housing which protects it shall be such that the action of the safety device is practically certain; yet at the same time the lamp shall not be too readily extinguished during normal service by the unnecessary operation of the device.
>
> (c) Headpiece lock or seal. - The lamp headpiece shall be provided with a lock or seal to prevent anyone from tampering with the safety device, the bulb, or the electrical contacts.
>
> (d) Battery container lock. - The battery shall be enclosed in a container that is equipped with a magnetic or other equally effective lock.

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[19] Bureau of Mines, Permissible Electric Cap Lamps, Procedure in Testing, Fees Charged, and Requirements for Approval: Sched. 6D, Dec. 21, 1935, pp. 4-5.

(e) Battery current restricted. - The amount of current flow between the conductors of the cord, if shortcircuited just outside of the battery casing or cord armor, shall be limited by the design of the battery or by a fuse inside the locked container to such a value as will not produce sparks that will ignite an explosive mixture of methane and air.

(f) It shall not be possible to obtain a difference of potential between any two accessible points of the cap lamp when assembled for use.

The requirements that must be met for flashlights to pass the permissible test are given below:[20]

The flashlight will be examined and tested in respect to safety only:

1. It shall be provided with a safety device which, when the bulb is broken, will prevent the heated bulb filament from igniting an explosive mixture of methane and air. The design of the safety device and the housing which protects it shall be such that the action of the safety device is practically certain; yet at the same time the light shall not be too readily extinguished during normal service by the unnecessary operation of the device.
2. The battery shall be of such design and capacity that it will not give electric sparks or arcs sufficient to ignite an explosive mixture of methane and air.
3. It shall not be possible to obtain a difference of potential between any two points on the outside of the flashlight casing.
4. Flashlights shall be durable in construction, practical in operation, and suitable for the conditions under which they are to be used.
5. Provision shall be made for sealing or adequately locking the battery container to prevent unauthorized removal of the battery underground or access to live battery terminals.

The main safety features of approved flashlights or hand lamps over those of cheaper types are their more rugged construction and the method by which the bulb is held in contact with the terminals leading to the battery In the ordinary lamp the bulb is screwed into a socket, whereas in the permissible lamp the socket is smooth and has no threads or catches; instead, a fairly strong spring tends to push the bulb out of the socket, and the heavy glass lens, metal band, clip, or wire is arranged so as to press against the top of the glass bulb and hold it down against the spring and in contact with the terminals. When the bulb of an ordinary flashlight or hand lamp is broken, the filament will continue to burn until it has "burned up," thus the heat will last long enough and be intense enough to ignite an inflammable mixture of natural gas. With an approved or permissible-type lamp the base is thrown out of contact the instant that the bulb is broken, and the filament will not remain at a high temperature long enough to ignite the gas.

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[20] Bureau of Mines, Permissible Electric Flashlights, Procedure in Testing, Fees Charged, and Requirements for Approval: Sched. 11A, Jan. 13, 1936, p. 3.

The approval list of the Federal Bureau of Mines includes unit flashlights, storage-battery cap lamps, and hand lamps using storage batteries or dry cells that have passed rigid tests as to use in explosive methane-air mixtures. Some of these lamps have also been approved by the Underwriters' Laboratories, Inc., for use in explosive gasoline vapor-air mixtures.

Although the storage-battery type of permissible cap lamp originally was developed for the mining industry, it is now being used in the petroleum industry as well. This lamp should be used in the petroleum industry not only because it is safer than other lighting equipment in an inflammable mixture of gas but also because it leaves both of the worker's hands free for sampling, climbing ladders (especially greasy and icy ones), using tools, etc., and gives superior illumination. A worker does not have to stop at intervals and move the lamp, nor does he have to work in the dark, as the direction of the illumination changes with his movements. Thus, the additional cost of the electric cap lamp is offset by increased convenience and dependability of illumination, which make possible more efficient and faster work. Many companies have found that the increased initial cost of the permissible cap lamp is more than offset also by the low cost of maintenance.

One of the plates used in the demonstration chamber is equipped with two lamp sockets designed to take the light bulbs used in permissible-type cap lamps. In one socket, which is of conventional type, the bulb can be secured in the same manner as in the socket of an automobile headlight. The second socket has no means of locking the bulb in the socket; instead it has a spring in the bottom which is compressed by pushing the base of the bulb into the socket, and the bulb is held in the socket and in contact with the terminals by a brass band placed over the top of the bulb. Back of each socket is a small plunger-type hammer that can be released to break the electric bulb. The plate, with the bulbs and hammers in place, is sealed in an inflammable mixture in the chamber and connected to a 6-volt battery. When the filament is glowing at white heat, the bulb that is inserted in the socket with arrangements similar to those for permissible lamps is broken by releasing the hammer, and the gas is not ignited because the glow of the filament ceases when the base of the bulb is ejected from contact with terminals. When the second bulb (the one in the conventional socket) is illuminated and broken, an ignition takes place immediately, and the filament continues to glow even after the explosion.

This experiment shows readily why nonpermissible or unapproved hand lamps are not safe. (Note: A similar arrangement would not make higher-voltage lamps safe because their filament would not cool fast enough to keep the heat from igniting the gas.)

SUMMARY

A fire or an explosion of inflammable gas or vapor can occur only when the volume of inflammable vapor bears a definite relationship to the volume of air (oxygen) present and when the mixture of the two gases is in contact with enough heat to raise it to the ignition temperature.

Vapors or gas from gasoline and crude oils are heavier than air and may travel down a hill or valley, or they may be carried by a gentle breeze for considerable distances (several hundred feet) to a source of ignition and the flame flash back to the source of the gas or vapor.

Gasoline burns or explodes and should not be used as a cleaning agent.

Fire can be extinguished by removing the air, the fuel, or the heat. In many fires that have occurred the igniting agents have been no larger than those used in the demonstrations described in this paper.

Nonpermissible or unapproved electric equipment should not be used where the atmosphere is or may become inflammable.

Only extension cords of approved types should be used; power lines or other electric wires should be located so that if they make contact with the ground, a metal surface, or each other, causing an arc, there will be no danger of their igniting an inflammable substance. If it is impossible to keep inflammable atmospheres from electric wires and switches, the proper type of cable or switch should be used or they should be installed in explosionproof fixtures.

Fuses, electric-light bulbs, drop-cord attachments, and similar devices should not be changed, plugged in, or adjusted with power in the circuit or a load on the line, if they are located near the source of inflammable vapors or gas. It is safer always to have the power or load off the circuit before making changes in electric equipment that may involve arcing or sparking.

Unapproved or nonpermissible flashlights or hand lamps, lighted matches, or cigarettes, or other open flames are dangerous near a source of inflammable vapor or gas.